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ADVANTAGES OF USING HYBRID VEHICLES BASED ON EMPIRICAL STUDIES ON THE CHASSIS DYNAMOMETER IN THE WLTC TEST

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Abstract

Vehicles powered in alternative ways have an increasing share in the car market. Their use is becoming more and more justified considering the ever more stringent standards for the emission of harmful substances from the exhaust systems of internal combustion engines and the introduction of restrictions on vehicle traffic in city centres. The possibility of using in the propulsion systems only an electric motor or its simultaneous use with the internal combustion engine enables a significant reduction of emission of harmful exhaust gas pollutants. This applies in particular to urban areas, where there are numerous exceedances of acceptable air quality standards. This problem is most noticeable in larger cities in Poland, where there is a lot of traffic. It is therefore legitimate to promote alternative vehicles powered in alternative ways. Their dual power system gives the opportunity to significantly reduce the emission of harmful substances. Therefore, the article presents own research, carried out on a chassis dynamometer, using two passenger cars, one with a spark-ignition combustion engine and the second with a hybrid drive system containing a spark-ignition engine and an electric motor (system without the possibility of recharging batteries from external sources). Vehicles were characterized by similar mass and the same displacement volumes of internal combustion engines. The results of the tests made it possible to compare cars in terms of exhaust emissions. For testing purposes, a chassis dynamometer was used, on which the WLTC homologation cycle was repeatedly reproduced. This is a new driving cycle, which replaces the NEDC cycle used so far in the type approval procedure in the European Union.

Keywords: *road transport, combustion engines, hybrid powertrains, air pollution, exhausts emissions*

1. Introduction

It is the fact that transport largely depends on petroleum derivative substances. The share of these fuels in producing energy in transport at the end of the 20th century accounted for as much as 97% [1]. Since then its share has not changed much [6]. The combustion of these fuels results in emission of exhaust gases, the main components of which include non-toxic substances: nitrogen, carbon dioxide and water vapour. Exhaust gases also comprise substances hazardous for people and the natural environment, such as nitrogen oxides, hydrocarbons, particulate matter and carbon monoxide [9].

With the implementation of more and more stringent standards, those emissions are gradually reduced, in particular in road transport [8]. However, these actions are insufficient all the time.

Therefore, it is necessary to increase the share of vehicles using alternative drive systems. One option is to increase the share of hybrid vehicles.

The article presents the advantages of using this type of vehicle in relation to a vehicle with a conventional spark-ignition engine. The comparative tests were carried out on a chassis dynamometer in a new one-cycle WLTC. This cycle is much more complex than NEDC, which was previously used in type approval procedures in Europe and should be a better reflection of real traffic conditions.

2. WLTP Procedure

The Worldwide Harmonized Light Vehicles Test Cycles (WLTC) is chassis dynamometer tests for the determination of emissions and fuel consumption from light-duty vehicles. The tests have been developed by the UN ECE GRPE (Working Party on Pollution and Energy) group. The WLTC cycles are part of the Worldwide Harmonised Light Vehicles Test Procedures (WLTP), published as UNECE Global technical regulation No. 15 (GTR 15). While the acronyms WLTP and WLTC are sometimes used interchangeably, the WLTP procedures define a number of other procedures – in addition to the WLTC test cycles, which are needed to type approve a vehicle [2, 4, 7, 10-12].

The WLTP replaces the European NEDC based procedure for type approval testing of light-duty vehicles, with the transition from NEDC to WLTP occurring over 2017–2019 [2, 5, 7, 10-12].

The WLTP procedures include several WLTC test cycles applicable to vehicle categories of different power-to-mass (PMR) ratio, as presented in Tab. 1. The PMR parameter is defined as the ratio of rated power (W) and curbs mass (kg). The curb mass (or kerb mass) means the "unladed mass" as defined in ECE R83. The cycle definitions may also depend on the maximum speed (v_max), which is the maximum speed of the vehicle as declared by the manufacturer (ECE R68) and not any use restriction or safety-based limitation. Cycle modifications are allowed to accommodate drivability problems for vehicles with power to mass ratios close to the borderlines or with maximum speeds limited to values below the maximum speed required by the cycle [2, 3, 7, 10-12].

Tab. 1. WLTC test cycles [2, 10-12]

Category	PMR, W/kg	v_max, km/h	Speed Phase Sequence
Class 3b	PMR > 34	v_max ≥ 120	Low 3 + Medium 3-2 + High 3-2 + Extra High 3
Class 3a		v_max < 120	Low 3 + Medium 3-1 + High 3-1 + Extra High 3
Class 2	34 ≥ PMR > 22	–	Low 2 + Medium 2 + High 2 + Extra High 2
Class 1	PMR ≤ 22	–	Low 1 + Medium 1 + Low 1

2.1. Class 3 Cycle

With the highest power-to-mass ratio, Class 3 is representative of vehicles driven in Europe and Japan. Class 3 vehicles are divided into 2 subclasses according to their maximum speed: Class 3a with v_max < 120 km/h and Class 3b with v_max ≥ 120 km/h. Selected parameters of the Class 3 cycles are given in Tab. 2, and the vehicle speed for Class 3b is shown in Fig. 1 (in this representation, Class 3a trace would look very similar) [2, 10-12].

2.2. Class 2 Cycle

Class 2 is representative of vehicles driven in India and of low power vehicles driven in Japan and Europe. Selected parameters of the Class 2 cycle are given in Tab. 3, and the vehicle speed is shown in Fig. 2 [2, 10-12].

Tab. 2. WLTC Class 3 cycles: selected parameters [2, 10-12]

Phase	Duration	Stop Duration	Distance	p_stop	v_max	v_ave w/o stops	v_ave w/ stops	a_min	a_max
	s	s	m	%	km/h	km/h	km/h	m/s²	m/s²
Class 3b (v_max ≥ 120 km/h)									
Low 3	589	156	3095	26.5	56.5	25.7	18.9	-1.47	1.47
Medium 3-2	433	48	4756	11.1	76.6	44.5	39.5	-1.49	1.57
High 3-2	455	31	7162	6.8	97.4	60.8	56.7	-1.49	1.58
Extra-High 3	323	7	8254	2.2	131.3	94.0	92.0	-1.21	1.03
Total	1800	242	23266						
Class 3a (v_max < 120 km/h)									
Low 3	589	156	3095	26.5	56.5	25.7	18.9	-1.47	1.47
Medium 3-1	433	48	4721	11.1	76.6	44.1	39.3	-1.47	1.28
High 3-1	455	31	7124	6.8	97.4	60.5	56.4	-1.49	1.58
Extra-High 3	323	7	8254	2.2	131.3	94.0	92.0	-1.21	1.03
Total	1800	242	23194						

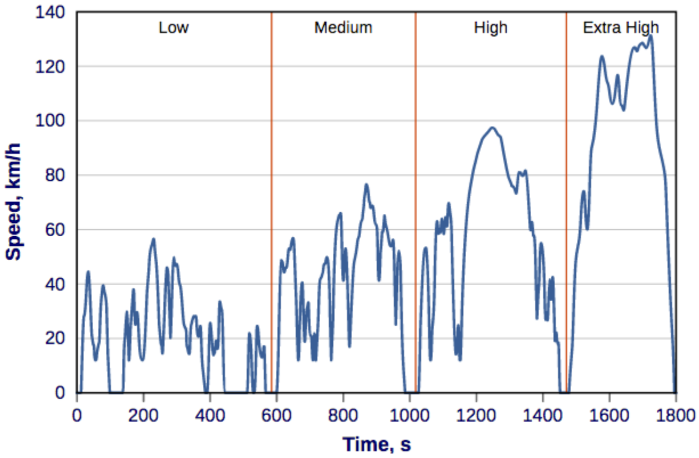

Fig. 1. WLTC cycle for Class 3b vehicles [2, 10-12]

Tab. 3. WLTC Class 2 cycle: selected parameters [2, 10-12]

Phase	Duration	Stop Duration	Distance	p_stop	v_max	v_ave w/o stops	v_ave w/ stops	a_min	a_max
	s	s	m	%	km/h	km/h	km/h	m/s²	m/s²
Low 2	589	155	3101	26.3	51.4	25.7	19.0	-0.94	0.90
Medium 2	433	48	4737	11.1	74.7	44.3	39.4	-0.93	0.96
High 2	455	30	6792	6.6	85.2	57.5	53.7	-1.11	0.85
Extra-High 2	323	7	8019	2.2	123.1	91.4	89.4	-1.06	0.65
Total	1800	240	22649						

2.3. Class 1 Cycle

With the lowest power-to-mass ratio, Class 1 is representative of vehicles driven in India. Selected parameters of the Class 1 cycle are given in Tab. 4, and the vehicle speed is shown in Fig. 3 [2, 10-12].

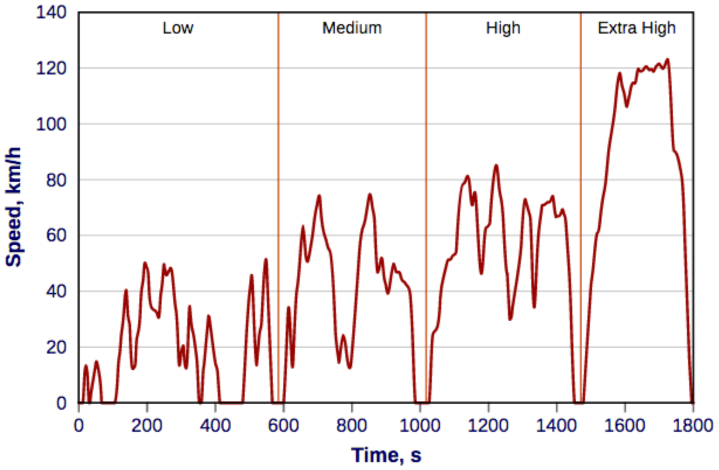

Fig. 2. WLTC cycle for Class 2 vehicles [2, 10-12]

Tab. 4. WLTC Class 1 cycle: selected parameters [2, 10-12]

Phase	Duration	Stop Duration	Distance	p_stop	v_max	v_ave w/o stops	v_ave w/ stops	a_min	a_max
	s	s	m	%	km/h	km/h	km/h	m/s²	m/s²
Low 1	589	154	3330	26.1	49.1	27.6	20.4	-1.00	0.76
Medium 1	433	48	4767	11.1	64.4	44.6	39.6	-0.53	0.63
Low 1	589	154	3330	26.1	49.1	27.6	20.4	-1.00	0.76
Total	1611	356	11428						

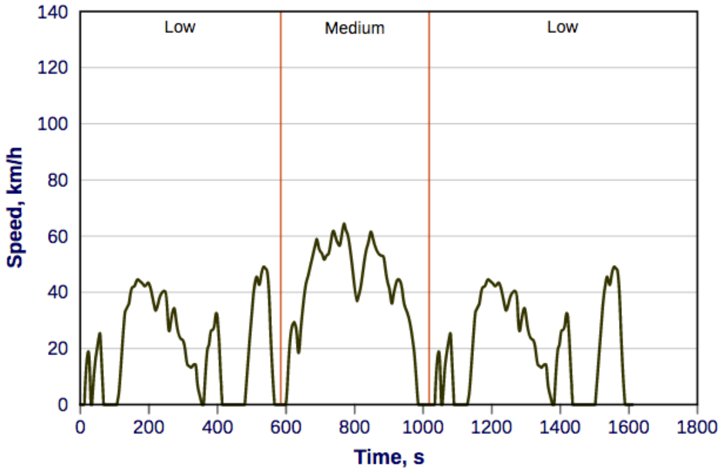

Fig. 3. WLTC cycle for Class 1 vehicles [2, 10-12]

3. Results of comparative studies

Two vehicles were tested on the chassis dynamometer. The first vehicle was equipped with a combustion engine with spark ignition. The second one was equipped with a series – parallel hybrid system. The hybrid vehicle was powered with a combustion engine with spark ignition combined with a generator. The power transmitted to the wheels comes from an electric motor that is synchronized with the continuously variable e-CVT transmission. Tab. 5 presents chosen technical parameters of both vehicles. Attention should be given to the fact that the difference in the weight of both vehicles was taken into account by selecting relevant load parameters of the chassis dynamometer.

Tab. 5. Chosen technical data of tested vehicles

	Vehicle with a petrol-fuelled engine	Hybrid vehicle
Engine displacement	1798 cm^3	1798 cm^3
Max. rated power	108 kW/6400 rpm	90 kW/5200 rpm
Max. torque	180 N·m/4000 rpm	142 N·m/3600 rpm
Compression ratio	11	13
Type of fuel injection	Multi-point (MPI)	Multi-point (MPI)
Gear box	e–CVT	e–CVT

The completed studies allowed for comparing distance-specific emission of pollutants and fuel consumption in the said vehicles with different drive systems. The tests were carried out on a chassis dynamometer in steady temperature and humidity conditions. The tests were repeated several times to verify the results and to obtain average values of the determined quantities. In the first part of the tests, a series of WLTC (Class 3) cycle repeats was performed for a vehicle with a spark-ignition engine subjected to a cold start-up (Fig. 4). Then a series of measurements for the warmed-up engine was made (Fig. 5). As a result, the average values of distance-specific pollutant emission and fuel consumption were determined, separately for cold start and warm start.

After testing a vehicle with a spark-ignition engine, tests were conducted for a hybrid vehicle. As in the previous case, also for the hybrid vehicle, measurements were made at the cold start-up (Fig. 6) and at the warm start-up of the engine (Fig. 7).

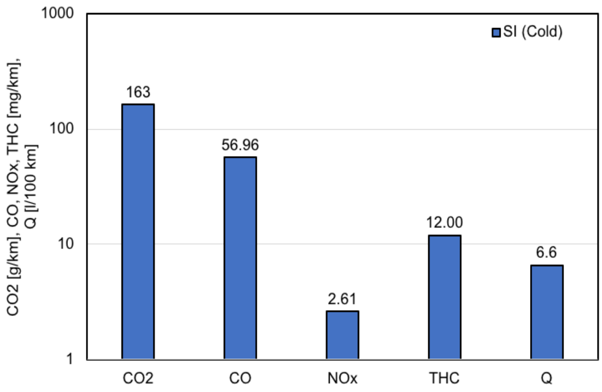

Fig. 4. Average results of exhaust emission and fuel consumption of the tested vehicle with a spark-ignition engine in WLTC – cold start-up procedure

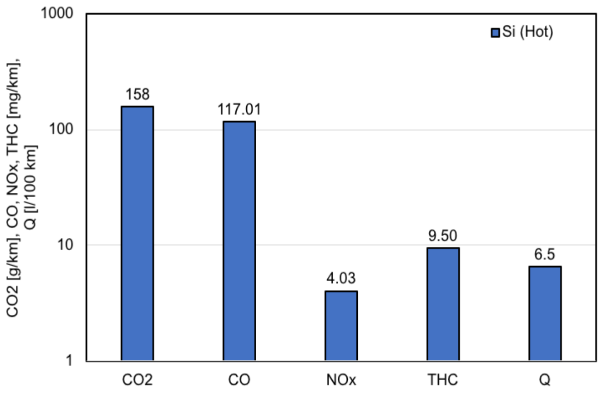

Fig. 5. Average results of exhaust emission and fuel consumption of the tested vehicle with a spark-ignition engine in WLTC – warm start-up procedure

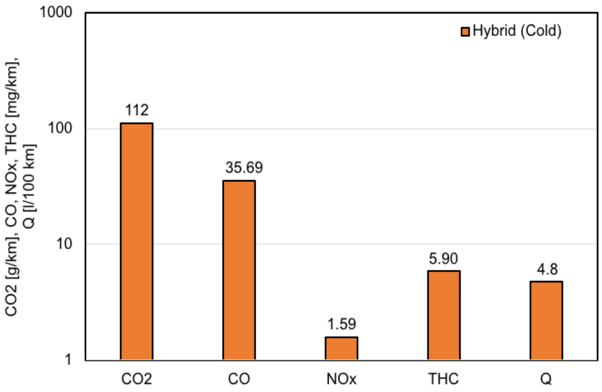

Fig. 6. Average results of exhaust emission and fuel consumption of the tested hybrid vehicle in WLTC – cold start-up procedure

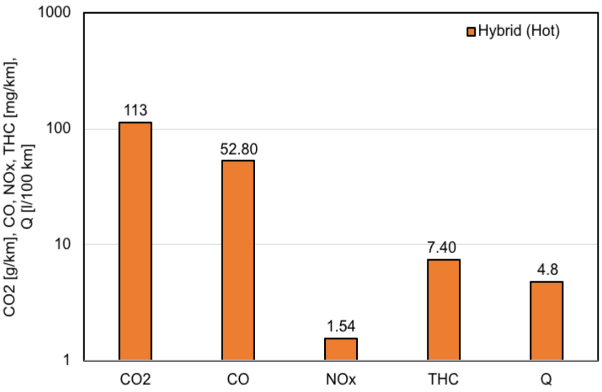

Fig. 7. Average results of exhaust emission and fuel consumption of the tested hybrid vehicle in WLTC – warm start-up procedure

Obtained results of emission of exhaust substances and fuel consumption for a vehicle with a spark-ignition engine and a hybrid vehicle allowed comparison of these two types of drive systems with each other. In the case of a cold engine start, the biggest difference is for a distance-specific emission of hydrocarbons – over 50%. In turn, for nitrogen oxides, it is almost 40%, and for carbon monoxide, a 37% lower for a hybrid vehicle. With regard to distance-specific emission of carbon dioxide and fuel consumption, lower values occur for a hybrid vehicle – the differences are just over 31% and 27%, to be exact (Fig. 8).

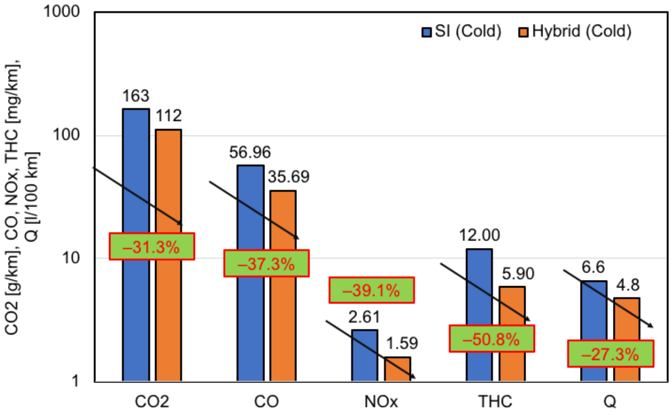

Fig. 8. Comparison of average exhaust emission and fuel consumption of a vehicle with spark-ignition engine and a hybrid vehicle in WLTC cycle – cold start-up procedure

A summary of results concerning emission of exhaust gas pollutants and fuel consumption for a vehicle with a spark-ignition engine and a hybrid vehicle in the case of warm engine was also prepared. This comparison shows that a hybrid vehicle is characterized by a lower emission of nitrogen oxides by more than 61%, hydrocarbons by more than 22% and carbon monoxide by almost 55%. The benefits of using a hybrid vehicle are also clearly visible in relation to carbon dioxide emission and fuel consumption. They were lower by over 28% and over 26%, respectively (Fig. 9).

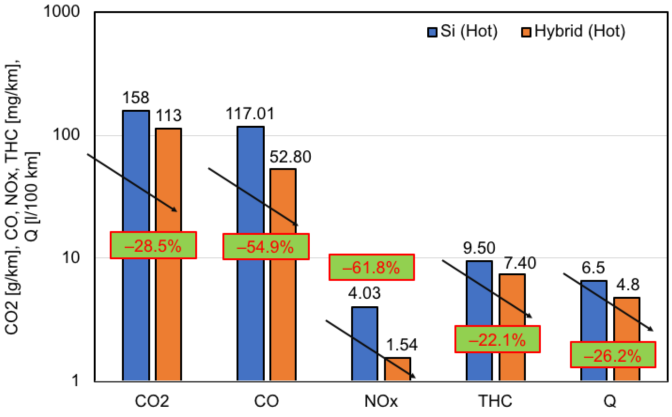

Fig. 9. Comparison of average exhaust emission and fuel consumption of a vehicle with spark-ignition engine and a hybrid vehicle in WLTC cycle, warm start-up procedure

4. Conclusions

The study presented in this article allowed for a comparison of two vehicles. The first vehicle was powered conventionally (spark-ignition engine) and the other was equipped with a hybrid drive. The conducted research and the analysis of the results show that the use of vehicles equipped with a hybrid system (electric and combustion engine) positively affects the emission of harmful exhaust substances and fuel consumption. It should be noted that on average, carbon dioxide emission was 30% lower, as was the fuel consumption. Another example is distance-specific emission of nitrogen oxides, which depends to a large extent on whether the engine has been warmed up or not before the tests. In the first case, the reduction of distance-specific emission of the said pollutant was lower by over 60%, while in the case of a cold engine – by an average of about 39%. A similar trend is also observed for road emission of hydrocarbons. The difference between a vehicle with a spark-ignition engine and a hybrid vehicle with a cold engine start is over 50%. However, when the engine is warmed up, this difference is only around 22%.

The results of tests clearly prove that hybrid vehicles in daily use may help reduce exhaust emission considerably and in consequence improve air quality, especially in towns and cities. For this reason, it is reasonable to promote the discussed alternative drive systems in vehicles.

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